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ABSTRACT

A series of studies was conducted to determine whether children's reasoning is capacity-limited and whether any such capacity, if it exists, is based on the working memory system. An N-term series (transitive inference) was used as the primary task in an interference paradigm. A concurrent short-term memory load was employed as the secondary task. In the first experiment, eight 7-year-olds performed the primary task while holding two digits or two colors in short-term memory. No interference was observed. In the second experiment, the preload was raised to four colors, which were required to be actively rehearsed throughout the primary task. As a secondary task, subjects were required to repeat the word "light" at a rate equivalent to articulatory effort in the memory load rehearsal. Results showed that active rehearsal did interfere with transitive inference. However, so did nonmnemonic articulation, although to a lesser extent. It was concluded that, while N-term series reasoning is capacity-limited, short-term memory is not used as a workspace. Using the easy-to-hard paradigm as a converging operation, the former conclusion was confirmed in the third experiment. Further exploration of the relationship between processing and storage showed that it is not a simple tradeoff but is influenced by similarity and proactive interference effects. (Author/RH)

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Working Memory and Processing Efficiency in Children's Reasoning

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Paper presented to the Conference of the Society for Research in Child Development, Toronto, Canada, April 25-28, 1985.

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Abstract

N-term series (transitive inference) was used as the primary task in an interference paradigm with a concurrent short term memory load as the secondary task. No interference was observed. Subsequent experiments showed that active rehearsal did interfere with transitive inference, but so did non-mnemonic articulation, although to a lesser extent. It was concluded that N-term series reasoning is capacity limited, but that short term memory is not used as a workspace. The former conclusion was confirmed using the easy-to-hard paradigm as a converging operation. Further exploration of the relationship between processing and storage showed that it is not a simple tradeoff but is influenced by similarity and proactive interference effects.

Working Memory and Processing Efficiency in Children's Reasoning

Graeme S. Halford, Murray T. Maybery

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This paper is concerned with two related issues. The first is whether children's reasoning is capacity-limited, and the second is whether any such capacity, if it exists, is based on the working memory system. We can address both these questions using a dual-task paradigm with reasoning as the primary task and short term memory as the secondary task.

The term capacity has been widely used in the cognitive development literature. However some usage has made it virtually synonymous with performance, so that any failure was seen as reflecting inadequate capacity. Some of the traditional Piagetian literature treated capacity this way. In other work, such as the early research by Pascual-Leone (1970), capacity was assessed by M-space measures, that were designed for the purpose. In yet other areas, such as memory development, capacity was regarded as the residual left when factors such as strategy and familiarity were controlled. None of these approaches has permitted capacity to be measured directly in a way that meets contemporary criteria in the adult cognition literature (Hunt & Lansman, 1982; Navon, 1984; Navon & Gopher, 1979). According to this approach, capacity is a resource which can be transferred from one task to another, and can be shared between tasks. Once task demands reach the limit of capacity available, increased demands by one task will produce a decrement in performance on the other task. Such a capacity can only be measured by dual-task paradigms.

Insofar as procedures for measuring capacity in cognitive development have been inadequate, claims that it remains constant from infancy, and competing claims that it increases with age, are equally unfounded. Furthermore empirical science is likely to be biased against a construct that cannot be measured. Concepts such as strategy and familiarity can be measured by contemporary experimental techniques, which makes it much easier to produce clear evidence of their operation. The fact that little such evidence exists for capacity may reflect little more than our inability to measure it.

Show slide 1 here

The dual-task interference paradigm is shown in slide 1. A primary and a secondary task are performed concurrently. Because simple single task-to-dual task deficits are difficult to interpret, the more developed versions of the paradigm use two levels of each task. If the two tasks are competing for a common capacity, the more difficult version of the secondary task produces a decrement in performance on the primary task, and vice verse. It has also been usual to assume that the decrement in performance due to the secondary task manipulation will be greater for the hard version of the primary task, producing an interaction between task difficulties as shown in slide 1. However work by Lane (1977) and by Wilson, Halford, Bain, Maybery and Kelly (paper submitted) has shown that the interaction does not always follow from capacity theory. The essential prediction is that increased demands by one task will produce some decrement in performance of the other task.

However there are still interpretational difficulties with this paradigm (Navon, 1984). For example, it is possible that interference

results not from competition for a common capacity, but because of specific characteristics of the tasks that result in one task producing outputs or side effects that interfere with the other. Although it is possible to counter some of Navon's criticisms of the paradigm (Wilson et al. paper submitted), the best safeguard is to use the Hunt-Lansman easy-to-hard paradigm as a converging operation. The easy-to-hard paradigm is not subject to the criticisms made by Navon.

Show slide 2 here

The easy-to-hard paradigm is based on individual differences. Basically, it attempts to assess whether individual differences in a hard primary task are capacity-dependent. The easy primary task is performed jointly with a secondary task. Either of these tasks could be performed alone without taxing the capacity of the participants (both are "data-limited", in the sense of Norman & Bobrow, 1975). However their joint performance does tax the capacity of at least some participants. Therefore the secondary task will reflect the capacity available. If performance on the hard primary task is capacity-limited, it should then be predicted by performance on the secondary task performed jointly with the primary task. However such prediction might be based, at least partly, on shared features of the tasks. To control for this, variance on the easy primary task, and the secondary task, each performed alone, is partialled out.

There are two important features of the easy-to-hard paradigm. The first is that specific task characteristics are controlled by partialling out. The second is that interference due to outputs of one task interfering with the other cannot explain the results. The reason is that the hard primary task is not performed jointly with a secondary task, and therefore

variance which is due to interferences between the easy primary task and the secondary task cannot explain the prediction of the hard primary task. Therefore the easy-to-hard paradigm is a useful way of checking results from the dual-task interference paradigm.

The second issue with which we are concerned is whether reasoning is limited by working memory limitations. We have considerable evidence that short term memory development, and particularly memory span, are the results of faster rehearsal rates, (Case, Kurland & Goldberg, 1982) which implies that they result from increased processing efficiency of some sort. But is this processing efficiency responsible for development of the capacity for reasoning? To answer this question we must explore the relationship between reasoning and short term memory. This can be done using the dual task paradigms we have been considering.

Since Atkinson & Shiffrin (1968) it has been common to assume that short term memory is the workspace of reasoning. However this assumption has been challenged recently by Klapp, Marshburn & Lester (1983), who found that if there was a 6.5 second delay between presentation of a memory load and presentation of a sentence verification task, then the latter task did not interfere with subsequent recall of the memory load. This is not due to transfer of the memory load information to long term memory, because presentation of a second memory load in place of sentence verification did interfere. It seems that if there was time to encode the memory preload before sentence verification began, there was no interference. This implies that sentence verification interferes with mnemonic encoding, but not with mnemonic storage. This interpretation is supported by a study by Halford, Bain and Maybery (1984), who found that a concurrent memory load interfered with N-term series reasoning if it was encoded during, but not if it was encoded before, reasoning began. However these results might

reflect relatively easy primary tasks, which did not impose significant loads on short term memory. Different results might be obtained with children, for whom the same tasks would be more difficult.

Show slide 3 here

We will address these problems firstly through a paradigm in which N-term series tasks are the primary task, and rehearsal and recall of information from short term memory is the secondary task. The paradigm is shown in slide 3. A preload is presented, recalled to check that it has been properly perceived, then the N-term series task is performed, and the preload is recalled. The N-term series task consisted on color-coded premises representing the series a>b, b>c, c>d, d>e. The premises were represented by four pairs of coloured pegs in the memory board. The task was to place two coloured tubes, containing different-length sticks, in the correct order according to the premises, in a similar fashion to the procedure used by Halford (1984). The easy version of the task used two-term problems, such as bc or cd, which can be solved using a single premise, b>c, or c>d. The hard version used three-term problems that required transitive inference. In this case participants had to place the pair bd in order, which entails integrating the premises b>c, c>d to construct the ordered triple bcd.

In the first experiment eight seven-year olds performed the primary task while holding two digits or two colours in short term memory. Active rehearsal of the STM load was not required. No interference between the tasks was observed, and there was no effect of whether the preload was digits or colours. This replicates the findings of Baddeley & Hitch (1974) who found that a subspan memory load which was not actively rehearsed did not

interfere with a concurrent cognitive task. However the 3-term series problem used in our experiment would have been close to the upper limit of participant's cognitive abilities, yet we still found no interference from a concurrent short term memory load. This suggests there is little trade-off between short term memory storage and reasoning.

Show slide 4 here

In the second experiment the preload was raised to four colours, which were required to be actively rehearsed throughout the primary task. There was also an articulation secondary task, in which participants were required to repeat the word "light" at a rate which was equivalent in terms of articulatory effort to the memory load rehearsal. The participants were 18 5-6 year olds. The latencies for the primary task are shown in slide 4.

There is a significant main effect of primary task difficulty, of secondary task difficulty, and an interaction of these factors, but this last effect is modified by an interaction with block, and is significant only in the first block of problems. This might mean that the interaction relfects metacognitive factors, such as learning to coordinate the two tasks. Alternatively it might mean that children learn to perform the two tasks in alternation, thereby preventing them from competing for capacity at the same time. We should note however that the main effect of secondary tasks, which is also evidence of competition for capacity, is not modified by order effects.

Show slide 5 here

The error data are shown in slide 5. Parametric considerations preclude an overall analysis, but there are significant differences among the three

secondary task conditions on hard primary task errors, and these are not modified by order effects.[1] This effect is certainly consistent with two tasks competing for a common capacity. Overall the results of experiment 2 suggest that N-term series reasoning is capacity-limited, but this conclusion must be accepted with caution until it is corroborated by further evidence.

Experiment 3 utilizes the Hunt-Lansman easy-to-hard paradigm. The easy task was the two-term series task, and the hard task was the three-term series task, as in experiments 1 and 2. The concurrent task was to rehearse four colours. Because it was expected to be difficult to instruct young children to give priority to one task, we were prepared to interpret either of the concurrent tasks as primary, and the other as an indication of capacity. This is compatible with the assumptions of the Hunt-Lansman model because both tasks are data-limited. The participants were 54 children aged 3- to 6-years.

Show slide 6 here

The results are shown in slide 6. The two dual tasks jointly predict performance on the hard, 3-term task, with variance on each of the predictor tasks performed separately controlled. It can also be seen that the strongest dual-task predictor is the two term measure, which predicts the hard three-term task with the separate tasks partialled out. In terms of the Hunt-Lansman model, these results indicate that performance on the three-term series task is capacity-limited. Furthermore the dual-task measures and the three-term measure all correlated significantly with age.

Experiments 2 and 3 together provide evidence that children's

three-term series reasoning is capacity limited. However they also indicate that the capacity for which the tasks competed was not specifically mnemonic, because the non-mnemonic articulation task in experiment 2 interfered with N-term series reasoning. Together with the fact that N-term series reasoning did not interfere with passive retention of information in short term memory in experiment 1, these results support previous research indicating that the tasks competed for processing rather than storage capacity.

The fact that there was so little tradeoff between processing and storage casts doubt on the proposal of Case, Kurland and Goldberg (1982) and Dempster (1981) that the growth of memory span might reflect increased processing efficiency, which thereby leaves more capacity available for storage. Such an hypothesis implies a processing-storage tradeoff for which there is little evidence. Consequently we decided to explore this factor further.

Case, Kurland and Goldberg (1982) have shown that the Case card-counting span, like the traditional memory span, is a function of processing efficiency. Consequently, the counting of cards should interfere with concurrent storage of information, if the proposed tradeoff between processing and storage exists. We therefore decided to construct a dual task version of the card-counting task to test this proposition.

Show slide 7 here

The basic design of the task is shown in slide 7. Children were presented a preload of digits, using ascending series so their preload span could be determined. Then one or more cards containing dots were counted, and the preload digits were recalled. The effect of counting on

span is shown in slide 8. There is the expected age effect, but a decline in span as a function of number of cards counted between presentation and recall. This would be expected according to the hypothesis of Case et al, (1974) or Dempster, but not according to the work of Baddeley & Hitch, Klapp et al, (1983), or Halford et al (1984). We also measured participants card counting and rehearsal rates and found that they jointly account for all the age variance on the recall task.

Show slide 8 here

There are several factors that might explain this discrepancy. We did check similarity, and found it to have an effect, but it was not large enough to explain the results and did not interact with any other effects. However it is possible that counting for an extended period simply interferes with rehearsal. Alternatively, the results might reflect proactive interference, which is known to be a potent factor in this type of task (Keppel & Underwood, 1962). On the other hand, if there is a genuine tradeoff between processing and storage, then difficulty of the intervening task should be a potent factor.

We tested these competing hypotheses in an experiment where children were given a preload consisting of 6 words from a common category. Then they were shown a pair of numbers, and had to subtract the right number from the left in the difficult task. In the easy task they were shown the same pair of numbers repeated four times, and asked to read them (to equalize the durations of the two levels of task). In the distributed condition they worked on the intervening task for five seconds, followed by five seconds for rehearsal, this cycle being repeated three times. In the massed condition they worded on the intervening task for 15 seconds,

followed by 15 seconds for rehearsal. The category of words changed every three trials, and the first trial on a new category provided the low proactive interference condition, while the third trial provided the high proactive interference data. Participants were 24 9-year olds.

Show slide 9 here

The results are shown in slide 9. There were main effects of processing difficulty, opportunity for rehearsal, and proactive interference, but there were no interactions between any of these effects. By far the largest effect is of proactive interference, and processing difficulty, though significant, is not sufficient in magnitude to suggest that tradeoff between storage and processing could be a major factor in the results of experiment four, or indeed, in memory development.

On the other hand we replicated the well-established finding that processing efficiency, as measured by rehearsal and counting rates, accounts for the age-variance in short-term recall. This finding makes it unnecessary to postulate that memory capacity, in the sense of size of the memory store, increases with age, but such a notion is in any case an anachrosim. However it in no way implies that processing capacity should not increase with age, and our results indicate that children's reasoning is limited by processing capacity.

From these results we draw four conclusions as shown in slide 10:-

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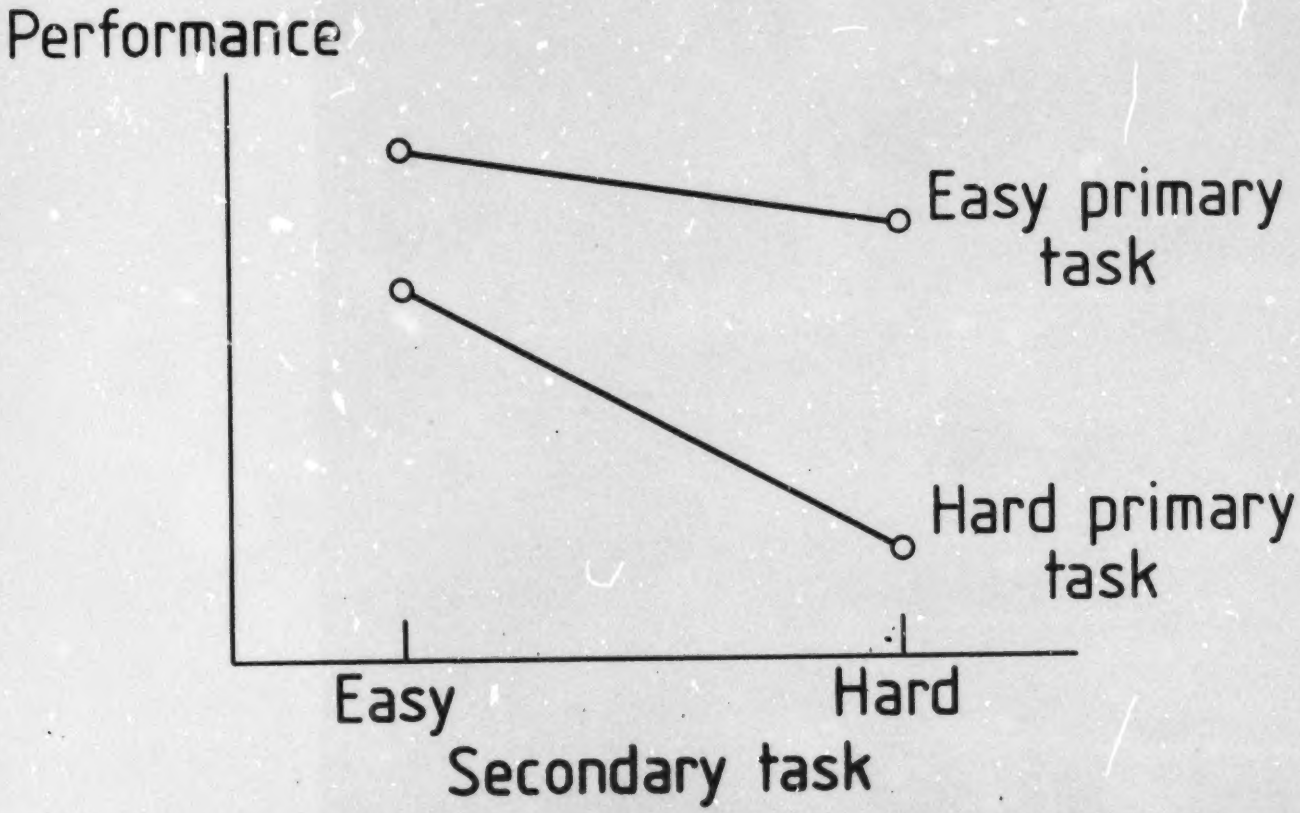
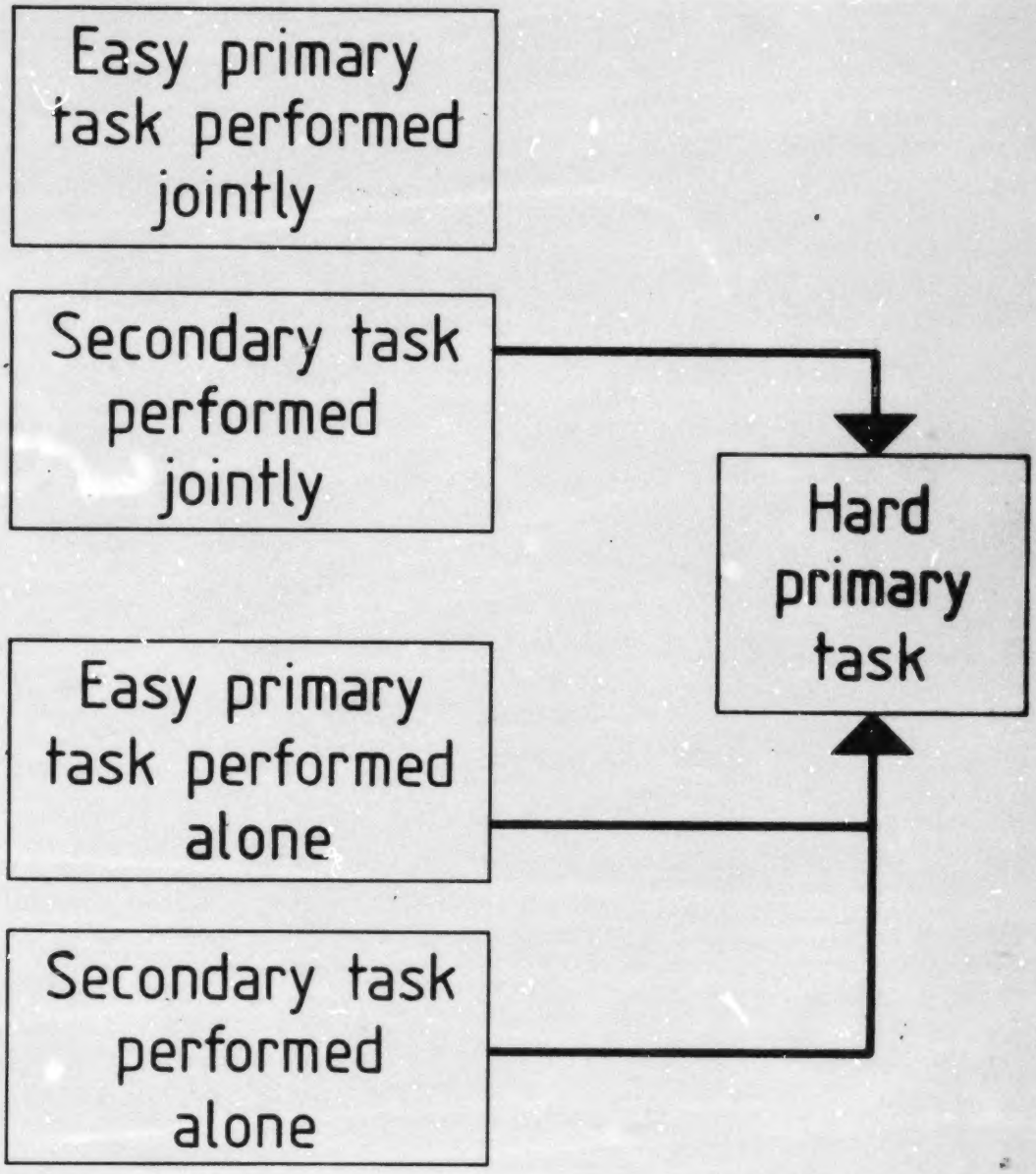
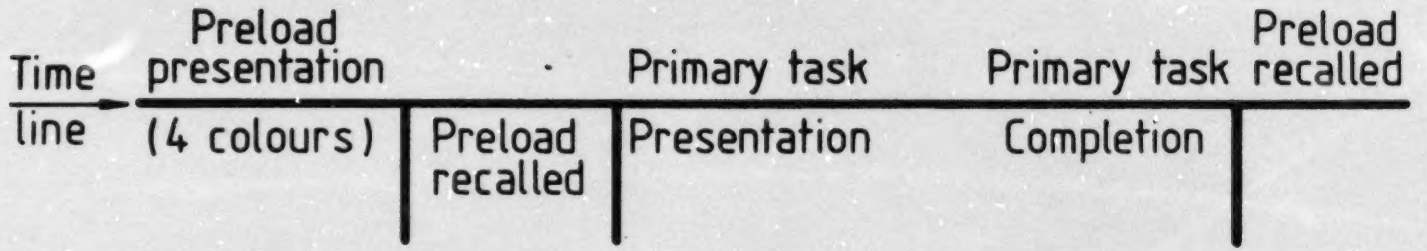
Show slide 10 here

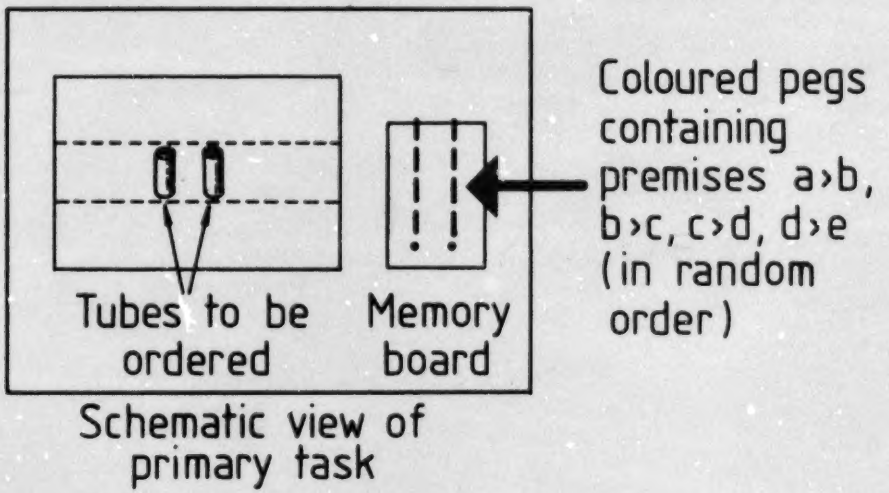
The dual task interference paradigm



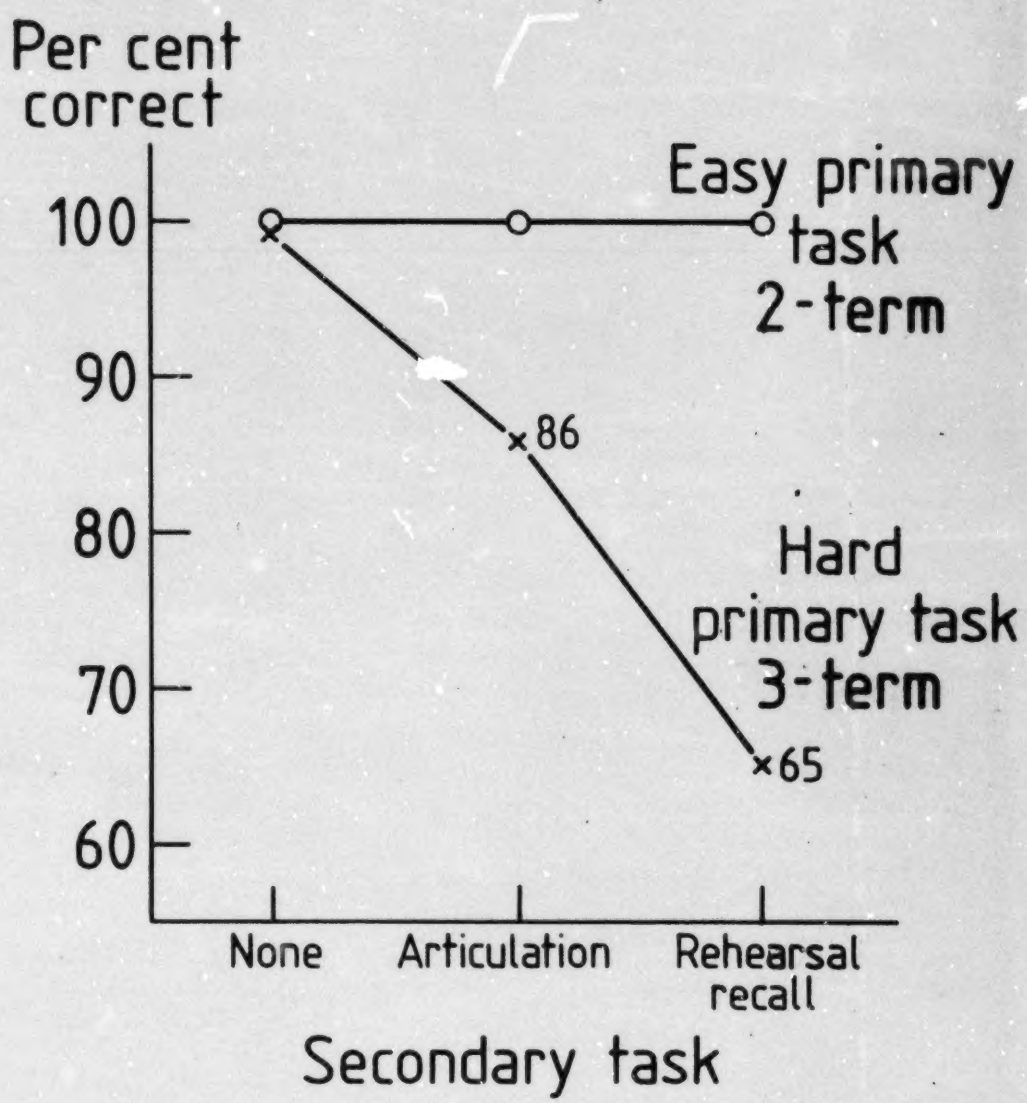
The easy-to-hard paradigm
(Hunt & Lansman, 1982)


Easy primary task performed jointly
Secondary task performed jointly
Hard primary task
Easy primary task performed alone
Secondary task performed alone





Schematic view of primary task


Per cent correct
100
90
80
70
60
Easy primary task 2-term
Hard primary task 3-term
86
65
None
Articulation
Rehearsal recall
Secondary task

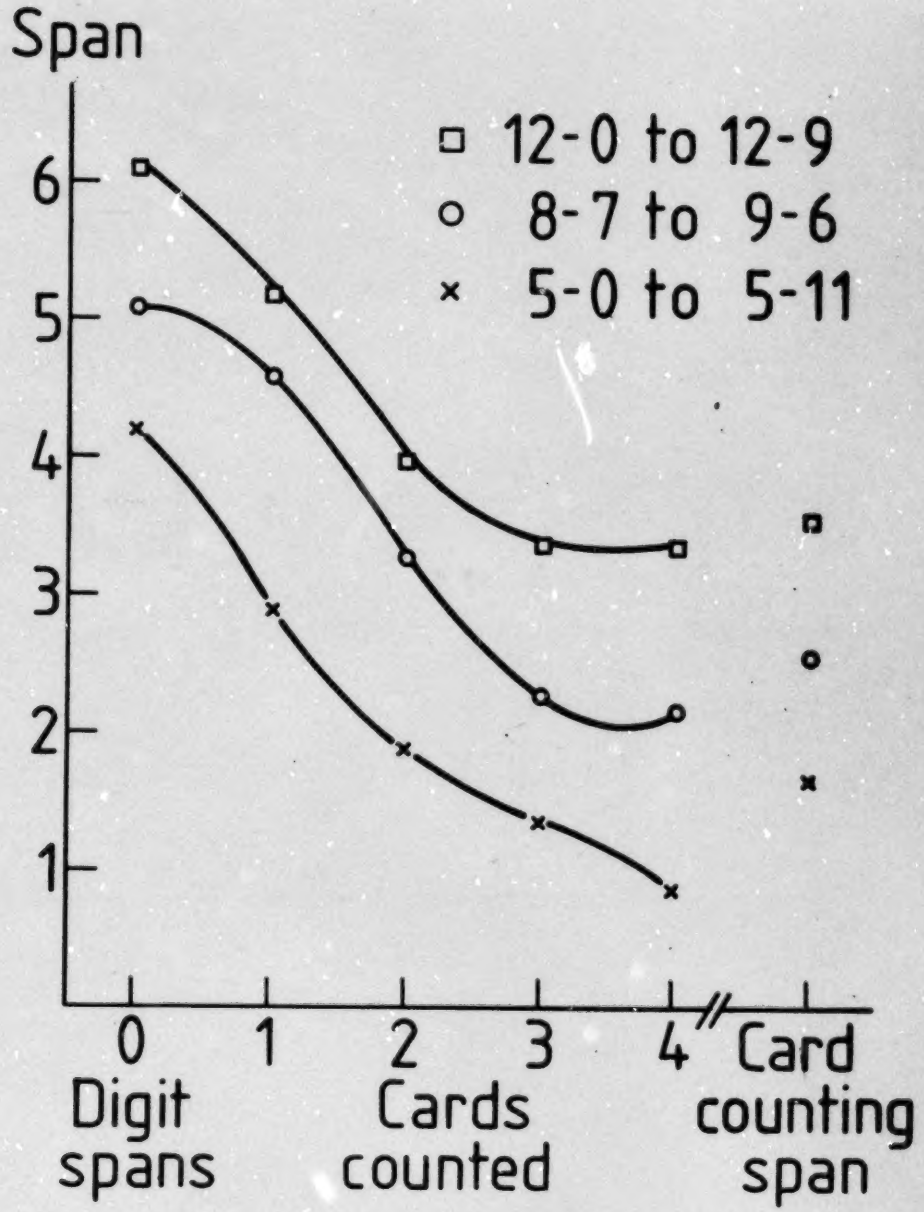
Slide 6

Separate tasks		Dual tasks						
Recall	2-term RT	Recall	2-term RT*	3-term RT*	percent variance	F	df	p
control	control	predictor	predictor	criterion	12.35	4.85	2,49	<.05
control	control	predictor	---	criterion	0.38	<1	1,50	NS
control	control	---	predictor	criterion	12.18	9.73	1,50	<.01

* errors were converted to RTS by assigning the longest RT by a participant for that type of problem to each problem on which an error occurred.

Slide 7

present preload digits	recall preload digits	count cards	recall preload digits


Span
6
5
4
3
2
1
□ 12-0 to 12-9
○ 8-7 to 9-6
× 5-0 to 5-11
0
1
2
3
4
Card
Digit spans
Cards counted
Card counting span

Slide 9

Experiment 5. Main effects of processing difficulty, opportunity for rehearsal, and proactive interference.

Mean recall scores

processing difficulty

	read	subtract
mean recall	3.57	3.30

opportunity for rehearsal

	distributed	massed
mean recall	3.59	3.28

proactive interference

	low	high
mean recall	4.11	2.76

Slide 10

1. Children's three-term series reasoning is capacity-limited.

2. The capacity for which N-term series and concurrent tasks compete is not short term memory storage, but processing capacity.

3. While there is some tradeoff between processing and storage, neither this nor previous research supports the hypothesis that it could be a major factor in the development of memory span.

4. The finding that span is a function of rehearsal rate argues against the idea that storage capacity increases with age, but is in no way incompatible with the hypothesis that processing capacity increases with age.

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Footnotes

1. Note this is not a ceiling effect, because the manipulation would pull the top curve down.